PRESENT AND FUTURE DIRECTIONS FOR ISOTOPE HYDROLOGY RESEARCH IN THE GEORGIA PIEDMONT

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INTRODUCTION

The techniques of isotope hydrology have been underutilized with respect to the study of the movement of natural water within the Georgia Piedmont Province. This is unfortunate because the processes which control groundwater movement and the generation of stream runoff within the Piedmont setting are in need of better resolution. Groundwater within the Georgia Piedmont is stored in an overlying porous media (the regolith or saprolite) and transported through fractured crystalline bedrock aquifers (Figure 1). The role of groundwater storage within the fractured bedrock has not as of yet been widely addressed, but is vital to the understanding of various aspects of the hydrodynamics and chemical dynamics of this system.

The isotopes of the water molecule (oxygen-16, oxygen-18, hydrogen, deuterium, and tritium) provide information which can be used to interpret the mechanisms of storage and rates of flow through Piedmont Province aquifers. The information provided from isotopic studies is vital not only to assessing hydraulic characteristics but also to understanding the fate (i.e. the kinetically controlled breakdown) of contaminants within the subsurface. In a prototype study for the Georgia Piedmont, environmental tritium was sampled and measured within a variety of natural water. The primary objective of this study was to better constrain the age of groundwater within this hydrological setting.

Determination of the age of groundwater has obvious implications for regional resource planning studies. Any reasonable groundwater resource management scheme will make certain that outflux does not exceed influx. The presence of tritium in groundwater indicates that a component of recharge has occurred within the past 30 years (or following the period of atmospheric hydrogen bomb testing which occurred during the 1950's and 1960's). Tritium data can therefore be used to determine whether a groundwater resource is derived from an active circulation system or whether the resource is "mined" (i.e. extracted at a rate greater than it is replenished through recharge).

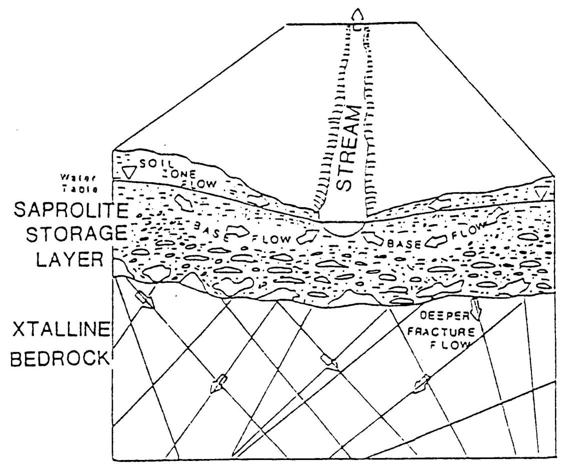

Figure 1. Idealized representation of groundwater flow within the Piedmont Province. Groundwater stored within the saprolite is discharged through stream channels and also recharges the deeper fractured crystalline rock aquifers (after Simmons and Heath, 1982).

METHODS

Ambient or environmental tritium was measured within 33 natural water samples. These samples were representative of most of the Piedmont Province hydrological system and included storm-event precipitation, surface water sampled during periods of baseflow, groundwater from wells completed within the regolith or saprolite, deeper groundwater from the fractured crystalline bedrock, and still deeper water from Warm Springs, Georgia (Figure 2). Two of the bedrock wells were not equipped with pumps and the samples from these wells are thought to represent resident water within the fractures. Three of the bedrock wells and one of the regolith wells were resampled approximately three months after the original sampling period. The average well-depth and saprolite thickness were respectively 75 and 20 meters; values which are representative of the Georgia Piedmont as a whole (Cressler et al., 1983 and Radtke et al., 1986). Several groundwater samples were included from the Blude Rige physiographic province for comparison. The Blue Ridge is characterized by the same underlying fractured crystalline rock but differs from the Piedmont Province with respect to its steeper slopes.

Tritium concentrations were measured by the Alberta Environmental Centre Laboratory using liquid scintillation counting following electrolytic enrichment in Ostlund cells. The precision of these anlyses was +/- 1 tritium unit (TU) or better. [Note: 1 TU = 1 tritium atom in 10^{18} atoms of hydrogen in water]. In addition to the tritium analyses, major ion analyses (summarized in Rose, 1990) were completed for most of the groundwater samples. A carbon-14 age-estimate was made from the dissolved inorganic carbon of the Warm Springs sample using benzene synthesis-liquid scintillation counting (Figure 2).

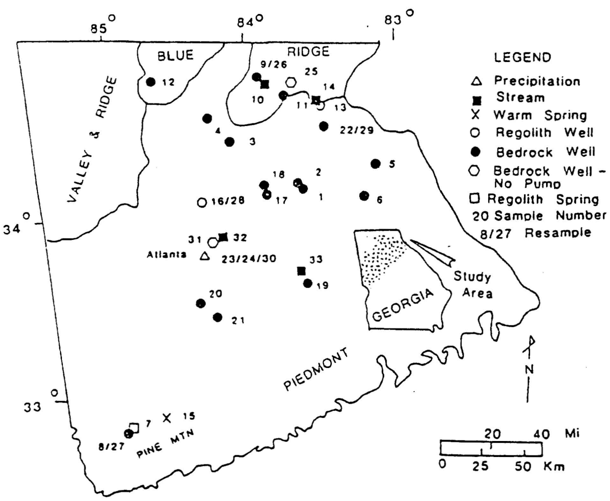

Figure 2. Map of the study area showing sampling locations.

RESULTS AND DISCUSSION

All groundwater from the bedrock aquifers was characterized by significant tritium concentrations (>1 TU) with the exception of the two wells which were not pumped and the warm spring. The average tritium concentration of groundwater sampled from the regolith (33 TU) was greater than the average of all other sample types (Figure 3). Tritium concentrations characteristic of the shallow domain (i.e. baseflow and regolith water) were many times greater than measured storm event precipitation (4-17 TU) and interpolated recent annual precipitation values (approximately 10 TU). This indicates that a significant component of groundwater is stored within the regolith for a period of approximately 25-35 years. Likely this water is mixed with more recent recharge.

This is important to the study of water resources within this region in that we now have a better idea of the period of time required for contaminants to reach a stream subsequent to subsurface infiltration. It is apparent that a contaminant can reach a stream channel within a period of a few decades or possibly less considering the role of hydrodynamic dispersion.
More stream water data, sampled on a time-series basis is needed to better constrain the residence time of groundwater before it becomes baseflow. Such knowledge will lead to a better understanding of the mechanisms of stream runoff, the principal water resource within this region.

Groundwater derived from the 18 production wells was generally less tritiated than water within the shallow hydrologic domain. Tritium concentrations representatitve of the fractured crystalline bedrock varied between 3 and 29 TU and averaged 20 TU. This is compared to the average value of 31 TU for shallow groundwater within the regolith. Recall that the two monitor wells completed within the fractured bedrock were non-tritatiated and these samples are believed to represent resident water within the fractures.

We therefore hypothesize that groundwater derived from a typical Piedmont Province production well is comprised of "modern" or "post-bomb" water stored within the saprolite and a small component of considerably older water residing within the fractured bedrock. The mechanism of fracture storage is not well understood but may involve the presence of numerous microscopic fractures characterized by limited asperity and interconnectivity. The tritium data indicate that regolith storage water is the major contributing source of groundwater comprising a well sample. This is a concept which has been intuitively apparent for many years (LeGrand, 1967; Trainer, 1987). The concept of fracture storage, however, has not been adequately addressed and may have important implications for well hydraualics, and groundwater resource development within the Georgia Piedmont.

Tritium concentrations in groundwater from two of the three production wells which were resampled at a three-month interval varied significantly (approximately 7-10 TU). This was probably not the result of seasonal tritium concentration variations in rainfall in that seasonal recharge likely mixes with a larger reservoir of previously stored groundwater prior to entering the fracture network. We interpret the temporal variation to result from the variable mixing of different proportions of tritiated water stored within the saprolite and less-tritiated or non-tritiated groundwater stored within the fractures. As pumping and recovery rates vary with each pumping cycle, the proportion of groundwater derived from each reservoir may likewise vary. This may result in the temporal variation observed with respect to tritium concentration at a given locality.

Groundwater from Warm Springs, Georgia was characterized by the lack of appreciable tritium and by a temperature of 32°C, far warmer than the 18-20°C range associated with the bedrock wells. Hewett and Crickmay (1937) proposed that the emergent springflow was driven to a depth of approximately 1 kilometer by the 150 meters of relief between the Pine Mountain recharge area and the outlet itself. This pronounced topographic relief, which creates the potential for deep, gravity-driven groundwater flow is rare within the Piedmont where slopes are typically less than 5%. The apparent carbon-14 age of the Warm Springs water (uncorrected for possible calcite dissolution) was 3,620 +/- 102 years. This may be the oldest water which can be routinely sampled within the Georgia Piedmont.

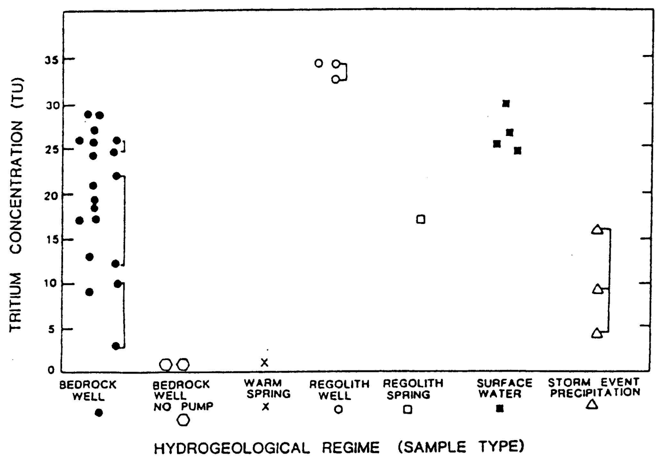

Figure 3. Tritium concentration variations within the Piedmont hydrological system. The vertical connecting bars indicate measurements from two sampling periods.

SUMMARY

The results of this study indicate that the residence time of groundwater within the Georgia Piedmont is indeed limited. A post-bomb test component of recharge is prevalent throughout the hydrological domain. The residence time of groundwater within the Georgia Piedmont is controlled by the high drainage density, limited fracture interconnectivity (?), the subdued topographic relief which limits regional gravity-driven flow, and well-pumping which serves to short-circuit flow paths.

Few water table maps exist for this area and therefore we do not presently have an adequate understanding of the regional extent of groundwater flow systems. We have not clearly delineated recharge areas and discharge areas, information vital to ground-water resource management. Given limited basic hydrological information, the interpretation of corroborative isotopic data becomes difficult but seemingly all the more vital. This study has clearly shown the potential for tritium to reveal pertinent hydrological information. It is apparent from these results that surface contamination can migrate through the fracture network and pollute a well within a period of decades. However, the areal extent of such migration is likely limited within the confines of local surface watersheds.

RECOMMENDATIONS FOR FUTURE RESEARCH

Future studies should be directed at determining the isotopic variability of surface water and groundwater within a given watershed. The data collection for this study was purposely "shot-gun" in approach in that this was a prototype study for the region. Both tritium and stable-isotopic data need be considered in future studies. We need to direct our use of stable isotopes and tritium to assess the mechanisms of year-round runoff generation within this locale in that stream runoff is our primary water resource. Future isotopic studies will prove helpful in constraining the residence time of groundwater and will lead to a better understanding of the dynamics of solute acquisition and the mechanisms of stream runoff generation within this setting. These are considerations which are central to water-quality dynamics and resource development within the Georgia Piedmont.

ACKNOWLEDGMENTS

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